

## CLAIMS

- 1     1.     A storage medium that contains instructions executable by a computer system to  
2     configure the computer system as a garbage collector that reclaims for reuse memory al-  
3     located by a mutator executing on the computer system, wherein the garbage collector  
4     performs a plurality of successive marking cycles, in each of which the garbage collector:
  - 5         A)     performs a marking operation in which the garbage collector traces refer-  
6         ence chains from a root set and makes marks associated with respective  
7         objects thereby encountered;
  - 8         B)     thereafter performs a succession of collection space increments within the  
9         marking cycle;
  - 10        C)     repeatedly calculates a measure of the cumulative efficiency of collection  
11        that has taken place during the marking cycle and determines whether the  
12        cumulative efficiency thereby calculated satisfies a set of at least one  
13        marking-initiation criterion; and
  - 14        D)     if so, terminates that marking cycle and begins the next marking cycle.
- 1     2.     A storage medium as defined in claim 1 wherein one said marking-initiation crite-  
2     rion is that the cumulative efficiency has peaked.
- 1     3.     A storage medium as defined in claim 2 wherein one said marking-initiation crite-  
2     rion is that at least a threshold number of collections have occurred during the marking  
3     cycle.
- 1     4.     A storage medium as defined in claim 1 wherein the cumulative collection effi-  
2     ciency for a marking cycle is calculated as the ratio of an amount of memory reclaimed  
3     during that marking cycle to an amount of time taken to by collection during that marking  
4     cycle.

1 5. A storage medium as defined in claim 4 wherein, in determining the amount of  
2 memory reclaimed in a cycle, the garbage collector includes the memory reclaimed by all  
3 space-incremental-collection operations that take place after the end of that marking op-  
4 eration.

1 6. A storage medium as defined in claim 5 wherein:  
2 A) the garbage collector treats the heap as divided into regions; and  
3 B) the marking operation includes reclaiming regions in which all objects sat-  
4 isfy an unreachability criterion based on that marking operation's results.

1 7. A storage medium as defined in claim 6 wherein, in determining the amount of  
2 memory reclaimed in a cycle, the garbage collector includes the amount of memory re-  
3 claimed as part of the marking cycle's marking operation but omits any memory re-  
4 claimed by any space-incremental-collection operations that take place before the end of  
5 that marking operation.

1 8. A storage medium as defined in claim 4 wherein one said marking-initiation crite-  
2 rion is that the cumulative efficiency has peaked.

1 9. A storage medium as defined in claim 1 wherein:  
2 A) each of a plurality of the collection space increments reclaims a collection  
3 set within the heap; and  
4 B) the garbage collector bases the collection set's selection on the marks  
5 made by one said marking operation's results.

1 10. A storage medium as defined in claim 9 wherein:  
2 A) the garbage collector treats the heap as divided into regions, for which it  
3 maintains respective remembered sets that in the collection space incre-  
4 ments it uses to determine whether objects in the collection set are referred

5                   to from outside the collection set and are therefore potentially reachable;  
6                   and  
7            B)     the garbage collector additionally bases the collection set's selection on  
8                   the sizes of the remembered sets.

1    11.     A storage medium as defined in claim 9 wherein one said marking-initiation crite-  
2            rion is that the cumulative efficiency has peaked.

1    12.     A storage medium as defined in claim 11 wherein the marking operation occurs at  
2            least in part concurrently with the mutator's execution.

1    13.     A storage medium as defined in claim 12 wherein in each of a plurality of the col-  
2            lection space increments the garbage collector determines whether objects in an associ-  
3            ated collection set within the heap satisfy an unreachability criterion based on the mark-  
4            ing operation's results, evacuates potentially reachable objects from the collection set  
5            without evacuating any object thus identified, and reclaims the collection set.

1    14.     A storage medium as defined in claim 9 wherein the marking operation occurs at  
2            least in part concurrently with the mutator's execution.

1    15.     A storage medium as defined in claim 14 wherein in each of a plurality of the col-  
2            lection space increments the garbage collector determines whether objects in an associ-  
3            ated collection set within the heap satisfy an unreachability criterion based on the mark-  
4            ing operation's results, evacuates potentially reachable objects from the collection set  
5            without evacuating any object thus identified, and reclaims the collection set.

1    16.     A storage medium as defined in claim 14 wherein one said marking-initiation cri-  
2            terion is that the cumulative efficiency has peaked.

1 17. A storage medium as defined in claim 9 wherein in each of a plurality of the col-  
2 lection space increments the garbage collector determines whether objects in an associ-  
3 ated collection set within the heap satisfy an unreachability criterion based on the mark-  
4 ing operation's results, evacuates potentially reachable objects from the collection set  
5 without evacuating any object thus identified, and reclaims the collection set.

1 18. A storage medium as defined in claim 17 wherein one said marking-initiation cri-  
2 terion is that the cumulative efficiency has peaked.

1 19. A storage medium as defined in claim 1 wherein the marking operation occurs at  
2 least in part concurrently with the mutator's execution.

1 20. A storage medium as defined in claim 19 wherein one said marking-initiation cri-  
2 terion is that the cumulative efficiency has peaked.

1 21. A storage medium as defined in claim 19 wherein in each of a plurality of the col-  
2 lection space increments the garbage collector determines whether objects in an associ-  
3 ated collection set within the heap satisfy an unreachability criterion based on the mark-  
4 ing operation's results, evacuates potentially reachable objects from the collection set  
5 without evacuating any object thus identified, and reclaims the collection set.

1 22. A storage medium as defined in claim 1 wherein in each of a plurality of the col-  
2 lection space increments the garbage collector determines whether objects in an associ-  
3 ated collection set within the heap satisfy an unreachability criterion based on the mark-  
4 ing operation's results, evacuates potentially reachable objects from the collection set  
5 without evacuating any object thus identified, and reclaims the collection set.

1 23. A storage medium as defined in claim 22 wherein one said marking-initiation cri-  
2 terion is that the cumulative efficiency has peaked.

- 1    24.    For reclaiming for reuse memory allocated by a mutator executing on the com-  
2    puter system, a method comprising employing the computer system to performs a plural-  
3    ity of successive marking cycles, each of which includes:
- 4            A)    performing a marking operation by tracing reference chains from a root set  
5                    and making marks associated with respective objects thereby encountered;  
6            B)    thereafter performing a succession of collection space increments within  
7                    the marking cycle;  
8            C)    repeatedly calculating a measure of the cumulative efficiency of collection  
9                    that has taken place during the marking cycle and determining whether the  
10                  cumulative efficiency thereby calculated satisfies a set of at least one  
11                  marking-initiation criterion; and  
12            D)    if so, terminating that marking cycle and beginning the next marking cy-  
13                  cle.
- 1    25.    A method as defined in claim 24 wherein one said marking-initiation criterion is  
2    that the cumulative efficiency has peaked.
- 1    26.    A method as defined in claim 25 wherein one said marking-initiation criterion is  
2    that at least a threshold number of collections have occurred during the marking cycle.
- 1    27.    A method as defined in claim 24 wherein the cumulative collection efficiency for  
2    a marking cycle is calculated as the ratio of an amount of memory reclaimed during that  
3    marking cycle to an amount of time taken to by collection during that marking cycle.
- 1    28.    A method as defined in claim 27 wherein, the memory reclaimed by all space-  
2    incremental-collection operations that take place after the end of that marking operation  
3    is included in determining the amount of memory reclaimed in a cycle.
- 1    29.    A method as defined in claim 28 wherein:  
2            A)    the method includes treating the heap as divided into regions; and

- 3           B)     the marking operation includes reclaiming regions in which all objects sat-  
4                    isfy an unreachability criterion based on that marking operation's results.

1   30.     A method as defined in claim 29 wherein, the amount of memory reclaimed as  
2   part of the marking cycle's marking operation is included in determining the amount of  
3   memory reclaimed in a cycle, but the amount of memory reclaimed by any space-  
4   incremental-collection operations that take place before the end of that marking operation  
5   is not.

1   31.     A method as defined in claim 27 wherein one said marking-initiation criterion is  
2   that the cumulative efficiency has peaked.

1   32.     A method as defined in claim 24 wherein:

- 2           A)     each of a plurality of the collection space increments reclaims a collection  
3                   set within the heap; and  
4           B)     the collection set's selection is based on the marks made by one said  
5                   marking operation's results.

1   33.     A method as defined in claim 32 wherein the method includes:

- 2           A)     treating the heap as divided into regions and maintaining therefor respec-  
3                   tive remembered sets that in the collection space increments are used to  
4                   determine whether objects in the collection set are referred to from outside  
5                   the collection set and are therefore potentially reachable; and  
6           B)     additionally basing the collection set's selection on the sizes of the re-  
7                   membered sets.

1   34.     A method as defined in claim 32 wherein one said marking-initiation criterion is  
2   that the cumulative efficiency has peaked.

1 35. A method as defined in claim 34 wherein the marking operation occurs at least in  
2 part concurrently with the mutator's execution.

1 36. A method as defined in claim 35 wherein each of a plurality of the collection  
2 space increments includes determining whether objects in an associated collection set  
3 within the heap satisfy an unreachability criterion based on the marking operation's re-  
4 sults, evacuating potentially reachable objects from the collection set without evacuating  
5 any object thus identified, and reclaiming the collection set.

1 37. A method as defined in claim 32 wherein the marking operation occurs at least in  
2 part concurrently with the mutator's execution.

1 38. A method as defined in claim 37 wherein each of a plurality of the collection  
2 space increments includes determining whether objects in an associated collection set  
3 within the heap satisfy an unreachability criterion based on the marking operation's re-  
4 sults, evacuating potentially reachable objects from the collection set without evacuating  
5 any object thus identified, and reclaiming the collection set.

1 39. A method as defined in claim 37 wherein one said marking-initiation criterion is  
2 that the cumulative efficiency has peaked.

1 40. A method as defined in claim 32 wherein each of a plurality of the collection  
2 space increments includes determining whether objects in an associated collection set  
3 within the heap satisfy an unreachability criterion based on the marking operation's re-  
4 sults, evacuating potentially reachable objects from the collection set without evacuating  
5 any object thus identified, and reclaiming the collection set.

1 41. A method as defined in claim 40 wherein one said marking-initiation criterion is  
2 that the cumulative efficiency has peaked.

1 42. A method as defined in claim 24 wherein the marking operation occurs at least in  
2 part concurrently with the mutator's execution.

1 43. A method as defined in claim 42 wherein one said marking-initiation criterion is  
2 that the cumulative efficiency has peaked.

1 44. A method as defined in claim 42 wherein each of a plurality of the collection  
2 space increments includes determining whether objects in an associated collection set  
3 within the heap satisfy an unreachability criterion based on the marking operation's re-  
4 sults, evacuating potentially reachable objects from the collection set without evacuating  
5 any object thus identified, and reclaiming the collection set.

1 45. A method as defined in claim 24 wherein each of a plurality of the collection  
2 space increments includes determining whether objects in an associated collection set  
3 within the heap satisfy an unreachability criterion based on the marking operation's re-  
4 sults, evacuating potentially reachable objects from the collection set without evacuating  
5 any object thus identified, and reclaiming the collection set.

1 46. A method as defined in claim 45 wherein one said marking-initiation criterion is  
2 that the cumulative efficiency has peaked.

1 47. A computer system configured by stored instructions as a garbage collector that  
2 reclaims for reuse memory allocated by a mutator executing on the computer system,  
3 wherein the garbage collector performs a plurality of successive marking cycles, in each  
4 of which the garbage collector:

- 5 A) performs a marking operation in which the garbage collector traces refer-  
6 ence chains from a root set and makes marks associated with respective  
7 objects thereby encountered;
- 8 B) thereafter performs a succession of collection space increments within the  
9 marking cycle;



- 10           C)     repeatedly calculates a measure of the cumulative efficiency of collection  
11                   that has taken place during the marking cycle and determines whether the  
12                   cumulative efficiency thereby calculated satisfies a set of at least one  
13                   marking-initiation criterion; and  
14           D)     if so, terminates that marking cycle and begins the next marking cycle.

1    48.     A computer system as defined in claim 47 wherein one said marking-initiation  
2    criterion is that the cumulative efficiency has peaked.

1    49.     A computer system as defined in claim 48 wherein one said marking-initiation  
2    criterion is that at least a threshold number of collections have occurred during the mark-  
3    ing cycle.

1    50.     A computer system as defined in claim 47 wherein the cumulative collection effi-  
2    ciency for a marking cycle is calculated as the ratio of an amount of memory reclaimed  
3    during that marking cycle to an amount of time taken to by collection during that marking  
4    cycle.

1    51.     A computer system as defined in claim 50 wherein, in determining the amount of  
2    memory reclaimed in a cycle, the garbage collector includes the memory reclaimed by all  
3    space-incremental-collection operations that take place after the end of that marking op-  
4    eration.

1    52.     A computer system as defined in claim 51 wherein:

- 2           A)     the garbage collector treats the heap as divided into regions; and  
3           B)     the marking operation includes reclaiming regions in which all objects sat-  
4                   isfy an unreachability criterion based on that marking operation's results.

1    53.     A computer system as defined in claim 52 wherein, in determining the amount of  
2    memory reclaimed in a cycle, the garbage collector includes the amount of memory re-

3 claimed as part of the marking cycle's marking operation but omits any memory re-  
4 claimed by any space-incremental-collection operations that take place before the end of  
5 that marking operation.

1 54. A computer system as defined in claim 50 wherein one said marking-initiation  
2 criterion is that the cumulative efficiency has peaked.

1 55. A computer system as defined in claim 47 wherein:

- 2 A) each of a plurality of the collection space increments reclaims a collection  
3 set within the heap; and  
4 B) the garbage collector bases the collection set's selection on the marks  
5 made by one said marking operation's results.

1 56. A computer system as defined in claim 55 wherein:

- 2 A) the garbage collector treats the heap as divided into regions, for which it  
3 maintains respective remembered sets that in the collection space incre-  
4 ments it uses to determine whether objects in the collection set are referred  
5 to from outside the collection set and are therefore potentially reachable;  
6 and  
7 B) the garbage collector additionally bases the collection set's selection on  
8 the sizes of the remembered sets.

1 57. A computer system as defined in claim 55 wherein one said marking-initiation  
2 criterion is that the cumulative efficiency has peaked.

1 58. A computer system as defined in claim 57 wherein the marking operation occurs  
2 at least in part concurrently with the mutator's execution.

1 59. A computer system as defined in claim 58 wherein in each of a plurality of the  
2 collection space increments the garbage collector determines whether objects in an asso-

3     ciated collection set within the heap satisfy an unreachability criterion based on the mark-  
4     ing operation's results, evacuates potentially reachable objects from the collection set  
5     without evacuating any object thus identified, and reclaims the collection set.

1     60.     A computer system as defined in claim 55 wherein the marking operation occurs  
2     at least in part concurrently with the mutator's execution.

1     61.     A computer system as defined in claim 60 wherein in each of a plurality of the  
2     collection space increments the garbage collector determines whether objects in an asso-  
3     ciated collection set within the heap satisfy an unreachability criterion based on the mark-  
4     ing operation's results, evacuates potentially reachable objects from the collection set  
5     without evacuating any object thus identified, and reclaims the collection set.

1     62.     A computer system as defined in claim 60 wherein one said marking-initiation  
2     criterion is that the cumulative efficiency has peaked.

1     63.     A computer system as defined in claim 55 wherein in each of a plurality of the  
2     collection space increments the garbage collector determines whether objects in an asso-  
3     ciated collection set within the heap satisfy an unreachability criterion based on the mark-  
4     ing operation's results, evacuates potentially reachable objects from the collection set  
5     without evacuating any object thus identified, and reclaims the collection set.

1     64.     A computer system as defined in claim 63 wherein one said marking-initiation  
2     criterion is that the cumulative efficiency has peaked.

1     65.     A computer system as defined in claim 47 wherein the marking operation occurs  
2     at least in part concurrently with the mutator's execution.

1     66.     A computer system as defined in claim 65 wherein one said marking-initiation  
2     criterion is that the cumulative efficiency has peaked.

1 67. A computer system as defined in claim 65 wherein in each of a plurality of the  
2 collection space increments the garbage collector determines whether objects in an asso-  
3 ciated collection set within the heap satisfy an unreachability criterion based on the mark-  
4 ing operation's results, evacuates potentially reachable objects from the collection set  
5 without evacuating any object thus identified, and reclaims the collection set.

1 68. A computer system as defined in claim 47 wherein in each of a plurality of the  
2 collection space increments the garbage collector determines whether objects in an asso-  
3 ciated collection set within the heap satisfy an unreachability criterion based on the mark-  
4 ing operation's results, evacuates potentially reachable objects from the collection set  
5 without evacuating any object thus identified, and reclaims the collection set.

1 69. A computer system as defined in claim 68 wherein one said marking-initiation  
2 criterion is that the cumulative efficiency has peaked.

1 70. An electromagnetic signal that represents instructions executable by a computer  
2 system to configure the computer system as a garbage collector that reclaims for reuse  
3 memory allocated by a mutator executing on the computer system, wherein the garbage  
4 collector performs a plurality of successive marking cycles, in each of which the garbage  
5 collector:

- 6 A) performs a marking operation in which the garbage collector traces refer-  
7 ence chains from a root set and makes marks associated with respective  
8 objects thereby encountered;
- 9 B) thereafter performs a succession of collection space increments within the  
10 marking cycle;
- 11 C) repeatedly calculates a measure of the cumulative efficiency of collection  
12 that has taken place during the marking cycle and determines whether the  
13 cumulative efficiency thereby calculated satisfies a set of at least one  
14 marking-initiation criterion; and

15           D)     if so, terminates that marking cycle and begins the next marking cycle.

1     71.     An electromagnetic signal as defined in claim 70 wherein one said marking-  
2     initiation criterion is that the cumulative efficiency has peaked.

1     72.     An electromagnetic signal as defined in claim 71 wherein one said marking-  
2     initiation criterion is that at least a threshold number of collections have occurred during  
3     the marking cycle.

1     73.     An electromagnetic signal as defined in claim 70 wherein the cumulative collec-  
2     tion efficiency for a marking cycle is calculated as the ratio of an amount of memory re-  
3     claimed during that marking cycle to an amount of time taken to by collection during that  
4     marking cycle.

1     74.     An electromagnetic signal as defined in claim 73 wherein, in determining the  
2     amount of memory reclaimed in a cycle, the garbage collector includes the memory re-  
3     claimed by all space-incremental-collection operations that take place after the end of that  
4     marking operation.

1     75.     An electromagnetic signal as defined in claim 74 wherein:

- 2           A)     the garbage collector treats the heap as divided into regions; and  
3           B)     the marking operation includes reclaiming regions in which all objects sat-  
4                 isfy an unreachability criterion based on that marking operation's results.

1     76.     An electromagnetic signal as defined in claim 75 wherein, in determining the  
2     amount of memory reclaimed in a cycle, the garbage collector includes the amount of  
3     memory reclaimed as part of the marking cycle's marking operation but omits any mem-  
4     ory reclaimed by any space-incremental-collection operations that take place before the  
5     end of that marking operation.

1 77. An electromagnetic signal as defined in claim 73 wherein one said marking-  
2 initiation criterion is that the cumulative efficiency has peaked.

1 78. An electromagnetic signal as defined in claim 70 wherein:

2 A) each of a plurality of the collection space increments reclaims a collection  
3 set within the heap; and

4 B) the garbage collector bases the collection set's selection on the marks  
5 made by one said marking operation's results.

1 79. An electromagnetic signal as defined in claim 78 wherein:

2 A) the garbage collector treats the heap as divided into regions, for which it  
3 maintains respective remembered sets that in the collection space incre-  
4 ments it uses to determine whether objects in the collection set are referred  
5 to from outside the collection set and are therefore potentially reachable;  
6 and

7 B) the garbage collector additionally bases the collection set's selection on  
8 the sizes of the remembered sets.

1 80. An electromagnetic signal as defined in claim 78 wherein one said marking-  
2 initiation criterion is that the cumulative efficiency has peaked.

1 81. An electromagnetic signal as defined in claim 80 wherein the marking operation  
2 occurs at least in part concurrently with the mutator's execution.

1 82. An electromagnetic signal as defined in claim 81 wherein in each of a plurality of  
2 the collection space increments the garbage collector determines whether objects in an  
3 associated collection set within the heap satisfy an unreachability criterion based on the  
4 marking operation's results, evacuates potentially reachable objects from the collection  
5 set without evacuating any object thus identified, and reclaims the collection set.

1 83. An electromagnetic signal as defined in claim 78 wherein the marking operation  
2 occurs at least in part concurrently with the mutator's execution.

1 84. An electromagnetic signal as defined in claim 83 wherein in each of a plurality of  
2 the collection space increments the garbage collector determines whether objects in an  
3 associated collection set within the heap satisfy an unreachability criterion based on the  
4 marking operation's results, evacuates potentially reachable objects from the collection  
5 set without evacuating any object thus identified, and reclaims the collection set.

1 85. An electromagnetic signal as defined in claim 83 wherein one said marking-  
2 initiation criterion is that the cumulative efficiency has peaked.

1 86. An electromagnetic signal as defined in claim 78 wherein in each of a plurality of  
2 the collection space increments the garbage collector determines whether objects in an  
3 associated collection set within the heap satisfy an unreachability criterion based on the  
4 marking operation's results, evacuates potentially reachable objects from the collection  
5 set without evacuating any object thus identified, and reclaims the collection set.

1 87. An electromagnetic signal as defined in claim 86 wherein one said marking-  
2 initiation criterion is that the cumulative efficiency has peaked.

1 88. An electromagnetic signal as defined in claim 70 wherein the marking operation  
2 occurs at least in part concurrently with the mutator's execution.

1 89. An electromagnetic signal as defined in claim 88 wherein one said marking-  
2 initiation criterion is that the cumulative efficiency has peaked.

1 90. An electromagnetic signal as defined in claim 88 wherein in each of a plurality of  
2 the collection space increments the garbage collector determines whether objects in an  
3 associated collection set within the heap satisfy an unreachability criterion based on the

4 marking operation's results, evacuates potentially reachable objects from the collection  
5 set without evacuating any object thus identified, and reclaims the collection set.

1 91. An electromagnetic signal as defined in claim 70 wherein in each of a plurality of  
2 the collection space increments the garbage collector determines whether objects in an  
3 associated collection set within the heap satisfy an unreachability criterion based on the  
4 marking operation's results, evacuates potentially reachable objects from the collection  
5 set without evacuating any object thus identified, and reclaims the collection set.

1 92. An electromagnetic signal as defined in claim 91 wherein one said marking-  
2 initiation criterion is that the cumulative efficiency has peaked.

1 93. A garbage collector for reclaiming for reuse memory allocated by a mutator exe-  
2 cuting on the computer system, the garbage collector including:

- 3 A) means for performing a marking operation by tracing reference chains  
4 from a root set and making marks associated with respective objects  
5 thereby encountered;
- 6 B) means for thereafter performing a succession of collection space incre-  
7 ments within the marking cycle;
- 8 C) means for repeatedly calculating a measure of the cumulative efficiency of  
9 collection that has taken place during a marking cycle that begins with the  
10 marking operation and determining whether the cumulative efficiency  
11 thereby calculated satisfies a set of at least one marking-initiation crite-  
12 rion; and
- 13 D) means for, if so, terminating that marking cycle and beginning a subse-  
14 quent marking cycle.